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**WELD JOINT CONCEPTS FOR ON-ORBIT REPAIR OF SPACE STATION
FREEDOM FLUID SYSTEM TUBE ASSEMBLIES**

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INTRODUCTION AND BACKGROUND

Because Space Station Freedom (SSF) is an independent satellite, not depending upon another spacecraft for power, attitude control, or thermal regulation, it has a variety of tubular, fluid-carrying assemblies on-board. The systems of interest in this analysis provide breathing air (oxygen and nitrogen), working fluid (two-phase anhydrous ammonia) for thermal control, and mono-propellant (hydrazine) for station reboost.

The tube assemblies run both internally and externally with respect to the habitats. They are found in up to 50 ft. continuous lengths constructed of mostly AISI 316L stainless steel tubing, but also including some Inconel 625 nickel-iron and Monel 400 nickel-copper alloy tubing. The outer diameters (OD) of the tubes range from 0.25-1.25 inches, and the wall thicknesses between 0.028-.095 inches. The system operational pressures range from 377 psi (for the thermal control system) to 3400 psi (for the high pressure oxygen and nitrogen supply lines in the ECLSS).

SSF is designed for a fifteen to thirty year mission. It is likely that the TA's will sustain damage or fail during this lifetime such that they require repair or replacement. The nature of the damage will be combinations of punctures, chips, scratches, and creases and may be cosmetic or actually leaking. The causes of these hypothetical problems are postulated to be:

1. Faulty or fatigued fluid joints— both QD's and butt-welds;
2. Micro-meteoroid impacts;
3. Collision with another man-made object; and
4. Over-pressure strain or burst (system origin).

While the current NASA baseline may be to temporarily patch the lines by clamping metal c-sections over the defect, and then perform high pressure injection of a sealing compound, it is clear that permanent repair of the line(s) is necessary [Anderson 1991]. This permanent repair could be to replace the entire TA in the segment; or perhaps the segment itself, both alternatives being extremely expensive and risky. The former would likely require extensive EVA to release TA clamps and pose great risk to other engineering subsystems, and the latter would require major de-servicing of the Station.

DESIGN CONSIDERATIONS

For joining TA's in thin-walled pressure vessel applications the butt-weld is the preferred method because the resulting tube can be considered to transmit stress in the same manner as the original TA. The truth is, however, that when a metal is welded both the weld and the heat affected zone (HAZ) have different material properties than the base metal. This is true whether the application is tube welding or plate welding, or any other welding [Davies 1984, Masubuchi 1980, ASM 1985].

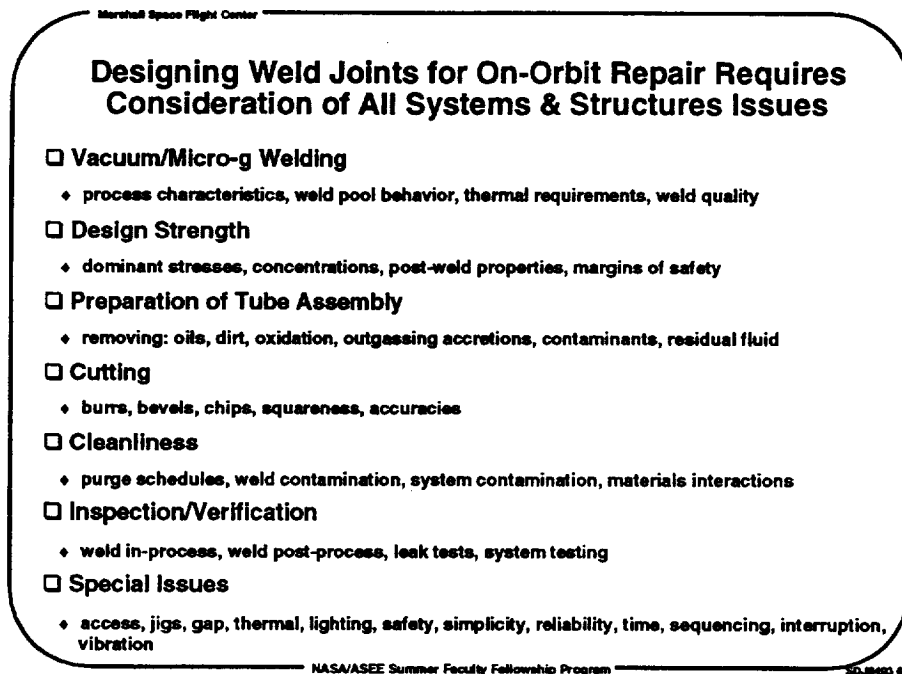


Figure 1. Issues for Design of Weld Joints for In-Space Repair

Figure 1 illustrates the drivers for the weld joint design. The conclusions of these considerations became then, the design criteria for the study.

The criteria are:

1. The weld joint design for in-space repair applications must provide much greater compliance (with respect to cutting the TA and the replacement) than the maximum allowable gaps of the standard butt-weld (.008 inches), perhaps on the order of .5 inches.
2. This compliance must be gained without surrendering weld quality and post-weld structural performance such that positive margin exists using the standard factor of safety for SSF.
3. The weld joint needs to be self-aligning and self-latching, as much as possible.
4. The hardware should be designed and fabricated with the astronaut's glove in mind, i.e. as large as is feasible, easy to handle.
5. The repair procedure and associated hardware design should minimize the required orbital support equipment.
6. If possible, the weld joint and weld procedure should minimize contact of the weld pool with the inside diameter of the tube assembly assuming that the fluid residuals are degrading to the weld process, or that subsequent cleaning of the TA interior is required to return to service.

DESIGN CONCEPTS

Considering the above design criteria, the most logical, generalized weld joint design to consider for in-space TA repair applications appears to be like that shown in Figure 2.

butt-weld used for terrestrial manufacturing of the SSF hard lines is definitely superior from a structural perspective compared to a union with $T_U < T_{U,optimal}$, but it is a difficult in-space repair technique for TA's.

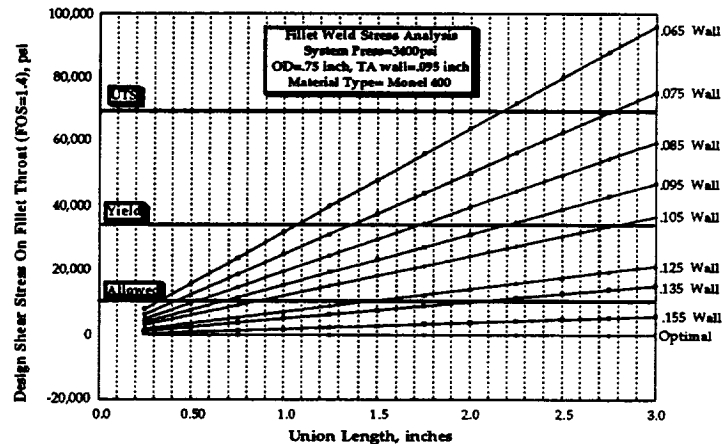


Figure 17. Analysis Yields Positive Margins for Near-Optimal Union Thicknesses

In summary, when:

- 1) $T_U < T_{U,optimal}$ the weld throat is shear stressed radially outward;
- 2) $T_U = T_{U,optimal}$ the weld throat has no shear stress (just hoop and axial stress); and
- 3) $T_U > T_{U,optimal}$ the weld throat is shear stressed radially inward.

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